

This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

**As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.**

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
7 February 2002 (07.02.2002)

PCT

(10) International Publication Number
WO 02/10702 A2

- (51) International Patent Classification⁷: **G01L 9/00**
- (21) International Application Number: **PCT/US01/22920**
- (22) International Filing Date: 20 July 2001 (20.07.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/627,946 28 July 2000 (28.07.2000) US
- (71) Applicant: **ABBOTT LABORATORIES [US/US]**; Dept. 377/AP6D-2, 100 Abbott Park Road, Abbott Park, IL 60064-6050 (US).
- (72) Inventor: **CHO, Steve, T.**; 1550 Vista Club Circle #301, Santa Clara, CA 95054 (US).
- (74) Agents: **WOODWORTH, Brian, R et al.**; Dept. 377/AP6D-2, 100 Abbott Park Road, Abbott Park, IL 60064-6050 (US).
- (81) Designated States (*national*): AU, CA, JP.
- (84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.



(54) Title: **MICRO-MACHINED ABSOLUTE PRESSURE SENSOR**

WO 02/10702 A2

(57) **Abstract:** A micro-machined absolute pressure sensor and process for making the same. A semiconductor membrane having a welled portion connected to a planar periphery is formed in recess in a silicon substrate through etching and boron diffusion. A dielectric pad is formed on a portion of the planar periphery, and a bonding layer of polysilicon or amorphous silicon is deposited over the semiconductor membrane and the dielectric pad. After an etching process that defines the outline of the semiconductor membrane, the bonding layer is bonded to a nonconductive substrate in a vacuum using electrostatic bonding or wafer bonding, forming a vacuum-sealed reference cavity. A first and a second conductor are disposed on an upper surface of the nonconductive substrate. The first conductor serves as a capacitor plate disposed within the reference cavity and is connected to a transfer lead that passes from the cavity. The transfer lead is electrically isolated from the semiconductor membrane by the dielectric pad. The second conductor is electrically connected to the semiconductor membrane. The semiconductor membrane and the capacitor plate store an electrical charge that varies as a function of the distance between the capacitor plate and the semiconductor membrane. The semiconductor membrane flexes in response to pressure, changing the capacitance and the charge, so as to indicate the pressure of external fluid acting on the semiconductor membrane.

MICRO-MACHINED ABSOLUTE PRESSURE SENSOR

Field of the Invention

The present invention generally concerns pressure sensors, and more particularly, concerns micro-machined absolute pressure sensors and a process for making the same.

Background of the Invention

The recent progress in micro-fabrication and micro-machining technologies is transforming the field of solid-state transducers, making possible the production of micro-electromechanical systems (MEMS). In general, MEMS refers to the integration of sensors, actuators, and electronics using techniques originating in the semiconductor industry to realize miniature, high-performance, low-cost, electromechanical systems, with minimum feature sizes measured in microns. Miniaturization of mechanical systems in this manner is particularly attractive, since micro-mechanical devices and systems are inherently smaller, lighter, faster, and usually more precise than their macroscopic counterparts. MEMS devices are typically developed using computer-aided design (CAD) techniques created to facilitate VLSI (very large scale integration) production, and are typically batch produced using VLSI-based fabrication tools. Like integrated circuits, MEMS devices are rapidly progressing toward smaller size, higher speed, and greater functionality. Furthermore, because of batch processing, another major benefit of MEMS technology is its ability to drive down component cost.

Examples of MEMS devices include miniature fluid-pressure sensors and flow sensors, accelerometers, gyroscopes, and micro-optical devices. With a projected market of several billion dollars, pressure sensors are among the most important MEMS devices. While a majority of the semiconductor-based pressure transducers employ piezoresistive elements, devices that measure pressure based on changes in capacitance have become the focus for new developments to achieve higher pressure sensitivity, lower temperature sensitivity, and reduced power consumption. As with typical capacitors, these devices generally include a pair of conductive elements that are separated by a space. One or both of the elements flexes in response to pressure variations, thereby causing the capacitance measured between the conductive elements to change.

A capacitive pressure sensor disclosed in U.S. Patent No. 4,853,699 has a generally hat-shaped semiconductor membrane that is attached around its periphery to a substrate to form a sealed reference cavity. A conductive pad is disposed within the reference cavity. When a voltage differential is applied between the conductive pad and the semiconductor membrane, a capacitive charge is stored by the device. As the external pressure changes,

the semiconductor membrane flexes, reducing the distance between the conductive elements, and thus changing the capacitance of the sensor.

In the method disclosed in the above-noted patent, the semiconductor membrane is fabricated by first forming a post of an etchable material on the surface of the substrate. Etchable silicon dioxide ridges at a height lower than the post are then formed on the substrate extending inwardly to contact the post. Polycrystalline silicon is deposited over the post and ridges, and the substrate is then etched to remove the post and the silicon dioxide ridges, leaving the polysilicon. This process forms a cavity with a plurality of channels extending therethrough. In order to seal the cavity, the substrate is exposed to a gas or vapor atmosphere, which causes growth of a material in the channels, closing them.

In many applications, it is necessary to measure pressure with a very high resolution, over a wide temperature range (e.g., -25°C through 85°C). Additionally, it is often necessary to sense absolute pressure. In order to monitor absolute pressure, a pressure transducer must include a vacuum-sealed reference cavity. Such a reference cavity cannot be obtained using the method and structure disclosed in the above-identified patent. No prior art MEMS devices are known that can provide a high resolution, absolute pressure measurement. Accordingly, it would be desirable to provide a capacitive micromachined absolute pressure sensor having a vacuum-sealed reference cavity. Additionally, it would be desirable to produce such a sensor using a batch process that reduces the number of processing steps and masks required, compared with prior art processing methods for producing similar devices.

Summary of the Invention

In accord with the present invention, an absolute pressure sensor including a vacuum-sealed reference cavity and method for making the sensor by micromachining a silicon substrate is provided. The sensor includes a flexible semiconductor membrane defining a cavity that is bonded to a substrate, preferably glass or silicon, under a high vacuum to form a vacuum-sealed reference cavity using a combination of eutectic and anodic bonding techniques. A first conductor is disposed within the cavity, and a transfer lead extends therefrom through the cavity wall. A nonconductive pad, preferably made of a dielectric material, is disposed between the transfer lead and the semiconductor membrane so as to electrically isolate the semiconductor membrane from the transfer lead. Additionally, a second conductor is connected to the semiconductor membrane. When a voltage differential is applied across the two conductors, a capacitive charge is built up between the first conductor and the semiconductor membrane. As the external pressure changes, the semiconductor membrane flexes, changing the distance between portions of the membrane and the first conductor, causing the capacitance to change.

The absolute pressure sensor is preferably fabricated using a batch manufacturing process. First, a plurality of cavities are formed in the top surface of a silicon wafer,

preferably by applying a first mask to the silicon wafer and bulk machining the silicon wafer with a chemical etchant. A semiconductor layer is then formed over the top surface of the silicon wafer and the plurality of cavities through boron diffusion. A plurality of dielectric pads are then formed adjacent to corresponding cavities using a second mask. Next, a nonconductive bonding layer is formed over the semiconductor layer and the plurality of dielectric pads by deposition of polysilicon or amorphous silicon. Material in proximity to each cavity is etched away from the silicon wafer using a third mask so as to define a plurality of individual sensor membranes. Each membrane comprises a welled portion connected to a planar periphery upon which a dielectric pad is disposed. The silicon wafer is next turned over, and the peripheries of the membranes are bonded to a nonconductive substrate, preferably glass, on the upper surface of which are disposed a plurality of conductors arranged so as to provide a pair of conductors for each sensor membrane. The silicon wafer and the nonconductive substrate are bonded in a vacuum so that when the bonding layer of each membrane is bonded to the top surface of the nonconductive substrate, a plurality of vacuum-sealed reference cavities are formed, each reference cavity having a pair of conductors extending therefrom. One of the conductors extends into the reference cavity and is electrically isolated from the membrane by the dielectric pad, and the other conductor is in electrical contact with the semiconductor membrane. Preferably, the conductors are produced by depositing gold on the nonconductive substrate. If the nonconductive substrate is glass, an electrostatic bonding process is performed that causes the gold to migrate into the bonding layer and form a eutectic seal with the glass. The dielectric pad prevents the gold from the lead connecting the conductor disposed in the cavity from reaching the semiconductor membrane, while a portion of the gold in the other conductor, which comprises a contact, migrates through the bonding layer to form an electrical contact with the semiconductor membrane. After bonding is completed, excess portions of the silicon wafer and the nonconductive substrate are removed to define the final shape of the sensor.

Brief Description of the Drawing Figures

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a process flow chart illustrating the processing steps used to fabricate an absolute pressure sensor in accord with the present invention;

FIGURE 2 is a cross-sectional view showing the construction of the absolute pressure sensor after a first processing step, in which a recess is etched into a silicon substrate and a semiconductor layer is formed;

FIGURE 3 is a cross-sectional view showing the construction of the absolute pressure sensor after a second processing step, in which a dielectric pad is deposited adjacent to the recess;

FIGURE 4 is a cross-sectional view showing the construction of the absolute pressure sensor after a third processing step, in which a bonding layer is deposited over the dielectric pad and the semiconductor layer;

FIGURE 5 is a cross-sectional view showing the construction of the absolute pressure sensor after a fourth processing step, in which bulk machining is performed to define an outline for the sensors membrane;

FIGURE 6 is a cross-sectional view showing the construction of the absolute pressure sensor after a fifth processing step, in which the bonding layer is bonded to a nonconductive substrate under a vacuum to form a vacuum-sealed reference cavity;

FIGURE 7 is a cross-sectional view showing the final configuration of the absolute pressure sensor after a sixth processing step, in which bulk machining is used to define the final shape of the sensors semiconductor membrane;

FIGURE 8 is a plan view showing the construction of the absolute pressure sensor after the second processing step;

FIGURE 9 is a plan view showing the construction of the absolute pressure sensor after the fourth processing step;

FIGURE 10 is a cross-sectional view taken along section line 10-10 of FIGURE 7, showing the positional relationship between the semiconductor membrane and a set of conductors disposed on the nonconductive substrate;

FIGURE 11 is a plan view showing a plurality of absolute pressure sensors being fabricated during the fourth processing step, using a batch process;

FIGURE 12 is a plan view showing an arrangement of a plurality of sets of conductors on the nonconductive substrate for use in the batch process; and

FIGURES 13A and 13B are cross-sectional views of the absolute pressure sensor illustrating (in a somewhat exaggerated manner) how the semiconductor membrane flexes, varying the capacitance of the sensor, in response to a change in external pressure.

Description of the Preferred Embodiment

With reference to FIGURES 1 and 2, the process for manufacturing an absolute pressure sensor in accord with the present invention begins with a first processing step 10, in which a semiconductor membrane 12 is formed on a silicon substrate 14. In general, a plurality of pressure sensors of the type described below are preferably manufactured in a batch process following steps somewhat like those used in semiconductor manufacturing processes. Accordingly, silicon substrate 14 will typically comprise a four-, six-, or eight-inch silicon wafer on which a plurality of absolute pressure sensors are fabricated. However, for simplicity, manufacturing steps for fabricating only a single sensor are

shown in FIGURES 2-7 and described below. In addition, it will be understood that the various layers comprising the absolute pressure sensor are very thin, but for clarity, the dimensions of these layers as shown in the Figures are much exaggerated.

During first processing step 10, a first mask is applied to silicon substrate 14 defining a recess 16 (indicated by the bold width line in FIGURE 2), which is etched into silicon substrate 14 using a conventional bulk-machining etching process, such as chemical etching with potassium hydroxide (KOH). After silicon substrate 14 is etched, semiconductor membrane 12 is formed over a portion of the upper surface of the silicon substrate and recess 16 through boron diffusion carried out at a temperature of about 1150° C for 1-15 hours. It is important to note that semiconductor membrane 12 only comprises a layer of semiconductor material at this point, but will be formed into a membrane during later processing. The duration of the boron diffusion process occurring at this elevated temperature is selected to produce a desired membrane thickness, which preferably will be in the range of 2-10 microns.

With reference to FIGURES 3 and 8, a second mask is used to form a lead transfer dielectric pad 20 over a peripheral portion of semiconductor membrane 12, as indicated in a second processing step 18 (in FIGURE 1). During this step, a 300-700 angstrom thick layer of nitride is deposited using a low pressure chemical vapor deposition (LPCVD) of dichlorosilane (SiH_2Cl_2) in the presence of ammonia (NH_3), at a pressure of about $\frac{1}{2}$ Torr and at a temperature of about 820°C. The deposited nitride comprises a dielectric material, meaning that it is a good electrical insulator, yet also is a good supporter of electrostatic fields. As explained in detail below, lead transfer dielectric pad 20 is used to electrically isolate a lead transfer conductor from semiconductor membrane 12. Accordingly, in addition to deposition of the nitride, an oxidation layer may be formed atop lead transfer dielectric pad 20 to further improve the electrical isolation characteristics of the pad. As shown in FIGURE 8, lead transfer dielectric pad 20 comprises a substantially rectangular pad covering a portion of the periphery of semiconductor membrane 12.

During a third processing step 22, a bonding layer 24 preferably having a thickness in the range of about 500-5000 angstroms is deposited over semiconductor membrane 12 and lead transfer dielectric pad 20, as shown in FIGURE 4. Bonding layer 24 preferably comprises either polysilicon or amorphous silicon and is deposited on membrane 14 using LPCVD, plasma enhanced chemical vapor deposition (PECVD), atmospheric pressure chemical vapor deposition (APCVD), or by sputtering. For example, a bonding layer of polysilicon can be formed using the LPCVD of silane (SiH_4) at a temperature of about 560° C.

Next, during a fourth processing step 26 (in FIGURE 1), material volumes 28 and 30 are removed from the periphery of the silicon substrate, semiconductor membrane, and bonding layer using bulk machining to a depth that is preferably about 6000 Angstroms

below the lower edge of semiconductor membrane 12 to define the external outline of semiconductor membrane 12 and bonding layer 24 for each sensor, as shown in FIGURES 5, 9, and 10. Preferably, this bulk-machining step is performed using reactive ion etching in a plasma reactor using a third mask to define the extent of the material removal.

In accord with a fifth processing step 34 (FIGURE 1) and as shown in FIGURE 6, silicon substrate 12 (i.e., the silicon wafer) is turned over and bonded to a nonconductive substrate 32, preferably comprising glass or silicon. This bonding step is carried out while the substrates are in a very-high vacuum (for example, less than one Torr) to produce a vacuum-sealed reference cavity 36 in each sensor. Also, this step is performed using a fourth mask to define the shape of the bonded surfaces. As shown in FIGURE 12, a plurality of sets of metal pads 38 are disposed on the upper surface of nonconductive substrate 32; each set of metal pads includes a lead transfer electrode 40 that extends from a capacitor plate 42 and a contact pad 44. Preferably, the metal pads comprise gold that is deposited onto the top surface of nonconductive substrate 32, using a conventional metal layering process such as LPCVD, PECVD, APCVD, or sputtering. As shown in FIGURE 10, nonconductive substrate 32 and silicon substrate 14 are aligned prior to the bonding step so that capacitor plate 42 is disposed toward the center of the recessed area of semiconductor membrane 12, and so that lead transfer electrode 40 is disposed adjacent to lead transfer dielectric pad 20, for each sensor. The type of bonding used is dependent upon the material used for nonconductive substrate 32. When nonconductive substrate 32 comprises glass, electrostatic bonding is preferably employed. However, when the nonconductive substrate comprises silicon, conventional silicon wafer bonding techniques are preferably employed.

The bonding process is performed in a manner that ensures an extremely low leak rate between reference cavity 36 and the ambient air surrounding each sensor when the sensor is returned to atmospheric pressure. This minimal leakage rate is achieved through a novel sealing process that represents a key aspect of the invention. During the bonding step, the gold in lead transfer electrode 40 migrates into bonding layer 24 and flows into any micro-voids that may exist between the bonding layer and the nonconductive substrate in the regions where the lead transfer electrode is disposed, thereby forming an eutectic seal where the lead transfer enters reference cavity 36. In contrast, anodic bonding is performed between the bonding layer and the nonconductive substrate in the regions outside of the lead transfer area. This anodic bonding forms an atomic scale seal that enables reference cavity 36 to be maintained at a high vacuum, preferably having a leak rate of less than about 10^{-16} standard cubic centimeters per minute (SCCM).

Another key aspect of the present invention is the electrical isolation between lead transfer electrode 40 and semiconductor membrane 12. As discussed above, the gold in lead transfer electrode 40 migrates into bonding layer 24, which comprises either

polysilicon or amorphous silicon, producing electrostatic bonding. In contrast, the nitride layer (and an optional oxide layer) in lead transfer isolation pad 20 prevents the gold from migrating into semiconductor membrane 12. As a result, semiconductor membrane 12 is electrically isolated from lead transfer electrode 40.

With reference to FIGURE 7, the final shape of a plurality of absolute sensors 48 are defined during a sixth processing step 46 (FIGURE 1), in which a major portion of silicon substrate 14 is removed using bulk machining (i.e., dissolved away through a chemical etching process). Dissolution of silicon substrate 14 is preferably performed by etching with ethylene diamine pyrocatechol water, KOH, or by an electrochemical polishing or etching process.

As discussed above, a typical manufacturing facility will perform processing steps 1-6 on a silicon wafer and a glass wafer, or a pair of silicon wafers, to form a plurality of absolute pressure sensors. Each sensor will preferably be approximately 0.75 mm square. After the wafer dissolution step, nonconductive substrate 32 is sawn to separate the sensors individually and/or into groups. It is contemplated that there may be some applications for which it is desirable to provide a group of two or three absolute pressure sensors formed on a single nonconductive substrate.

With reference to FIGURES 13A and 13B, absolute pressure sensor 48 operates in the following manner. A voltage differential is applied across lead transfer electrode 40 and contact pad 44, which is in electrical communication with semiconductor membrane 12. This voltage creates a charge "Q" between capacitor plate 42 and semiconductor membrane 12, since the semiconductor membrane serves as a second capacitor plate. The amount of charge Q stored by the capacitance of absolute pressure sensor 48 is dependent on two factors: the applied voltage differential and the distance between capacitor plate 42 and semiconductor membrane 12, i.e., the capacitance of the device. Accordingly, if the voltage differential is held constant, the charge, Q, of the device (or its capacitance) will be directly proportional to the distance between capacitor plate 42 and the semiconductor membrane 12.

Because of the thinness of semiconductor membrane 12 and bonding layer 24, the semiconductor membrane flexes when the pressure exerted by a gas or fluid surrounding the sensor exceeds the pressure in reference cavity 36. Since reference cavity 36 is maintained at a high vacuum (i.e., at a very low absolute pressure), the pressure sensor is able to determine absolute pressure of the surrounding gas or fluid. For example, if absolute pressure sensor 48 is placed in a moderately high vacuum having a pressure of P1, there is only a small pressure differential between the moderately high vacuum and the high vacuum in reference cavity 36. Consequently, there is very little flexing of semiconductor membrane 12, as shown in FIGURE 13A. As a result, a charge of Q1 can be stored by the absolute pressure transducer. With reference to FIGURE 13B, now suppose the pressure is raised to a much higher (near atmospheric) pressure level P2. The

larger pressure differential between the near atmospheric pressure applied externally to the semiconductor membrane and the high vacuum in reference cavity 36 causes semiconductor membrane 12 to flex inwardly, reducing the distance between portions of the semiconductor membrane and capacitor plate 42, thereby reducing the charge Q2 that can be stored by the device, due to its lower capacitance. By sensing the capacitance of the absolute pressure transducer (or sensing the charge stored by the device) using any of the readily calibrated electrical circuits designed for this purpose that are commercially available, an indication can be provided of the absolute pressure of any fluid to which the exterior of the absolute pressure sensor is exposed.

Although the present invention has been described in connection with the preferred form of practicing it, those of ordinary skill in the art will understand that many modifications can be made thereto within the scope of the claims that follow. Accordingly, it is not intended that the scope of the invention in any way be limited by the above description, but instead be determined entirely by reference to the claims that follow.

The invention in which an exclusive right is claimed is defined by the following:

1. A process for fabricating an absolute pressure sensor, comprising the steps of:

- (a) forming a semiconductor membrane on a substrate, said semiconductor membrane including a wellled portion within a recess formed in the substrate and a planar periphery surrounding the recess;
- (b) forming a substantially nonconductive pad over a portion of the planar periphery of the semiconductor membrane;
- (c) forming a bonding layer over the semiconductor membrane and the substantially nonconductive pad;
- (d) providing a generally planar nonconductive substrate having a first conductor and a second conductor formed thereon;
- (e) bonding the planar nonconductive substrate to the planar periphery of the semiconductor membrane in a vacuum so as to form a vacuum-sealed reference cavity in the recess having the first and second conductors extending therefrom, said first conductor extending into the reference cavity to form a capacitor plate and having a lead portion disposed adjacent to said nonconductive pad so as to be electrically isolated from the semiconductor membrane, said second conductor being in electrical communication with the semiconductor membrane; and
- (f) removing the substrate from the semiconductor membrane.

2. The process of Claim 1, wherein the step of forming the semiconductor membrane comprises the steps of:

- (a) forming the recess in a generally planar silicon material that comprises the substrate; and
- (b) depositing a semiconductor layer within the recess and on a periphery of the recess of the substrate to form the semiconductor membrane.

3. The process of Claim 2, further comprising the step of removing portions of the planar silicon material surrounding the recess by masking and chemically etching away the planar silicon material.

4. The process of Claim 1, wherein the step of forming the bonding layer comprises the step of depositing a layer of one of a polysilicon and an amorphous silicon over the semiconductor membrane.

5. The process of Claim 1, wherein the step of forming the substantially nonconductive pad comprises the step of forming a layer of a dielectric material over a portion of the planar periphery of the semiconductor membrane.

6. The process of Claim 5, further comprising the step of forming a layer of a nonconductive oxide over the layer of dielectric material.

7. The process of Claim 1, wherein the bonding layer has a thickness of about 5000 angstroms or less.

8. The process of Claim 1, wherein the planar nonconductive substrate comprises one of a glass, a ceramic, and a silicon material.

9. The process of Claim 8, wherein the planar nonconductive substrate is bonded to the bonding layer using electrostatic bonding.

10. The process of Claim 9, wherein the first and second conductors comprise gold, further comprising the step of causing the gold to migrate into the bonding layer so as to form a eutectic seal.

11. The process of Claim 10, wherein the gold from the second conductor migrates through the bonding layer and into the semiconductor membrane so that the semiconductor membrane is in electrical communication with the second conductor.

12. The process of Claim 10, wherein the gold from the first conductor is prevented from migrating into the semiconductor membrane by the substantially nonconductive pad.

13. The process of Claim 1, wherein the step of bonding the planar nonconductive substrate to the planar periphery comprises the step of forming an anodic bond between the bonding layer and the generally planar nonconductive substrate.

14. A process for concurrently making a plurality of absolute pressure sensors, comprising the steps of:

- (a) forming a plurality of recesses in a top surface of a silicon wafer;
- (b) forming a semiconductor layer that extends over the top surface of the silicon wafer and into the plurality of recesses;
- (c) forming a plurality of substantially nonconductive pads, one for each sensor, over the semiconductor layer;
- (d) forming a bonding layer over the semiconductor layer and the plurality of substantially nonconductive pads;
- (e) etching the silicon wafer away proximate to each cavity so as to define a plurality of semiconductor membranes, each semiconductor membrane comprising a welled portion and a surrounding planar periphery;

(f) providing a nonconductive substrate having a plurality of conductive pads disposed on an upper surface thereof, said plurality of conductive pads being arranged on the nonconductive substrate so as to define for each sensor membrane:

- (i) a capacitor plate connected to a lead transfer electrode; and
- (ii) a contact pad;

(g) bonding the silicon wafer to the nonconductive substrate in a vacuum so as to define a plurality of vacuum-sealed reference cavities, each reference cavity having a lead transfer electrode extending therefrom over one of the substantially nonconductive pads such that the lead transfer electrode is electrically isolated from the semiconductor membrane, each semiconductor membrane being in electrical communication with a corresponding contact pad; and

(h) dividing the silicon wafer and the nonconductive substrate into individual absolute pressure sensors and/or groups of absolute pressure sensors.

15. The method of Claim 14, wherein the step of forming the nonconductive bonding layer comprises the step of depositing a layer of one of a polysilicon and an amorphous silicon over the semiconductor layer and said plurality of substantially nonconductive pads.

16. The method of Claim 14, wherein the step of forming said plurality of substantially nonconductive pads comprises the step of using a mask to form a layer of a dielectric material over a specific peripheral portion of each of the semiconductor membranes.

17. The method of Claim 16, further comprising the step of forming a layer of an electrically non-conductive oxide over the layer of dielectric material.

18. The method of Claim 14, wherein the nonconductive substrate is bonded to the bonding layer using electrostatic bonding.

19. The method of Claim 18, wherein the lead transfer electrode and the contact pad comprise gold that migrates into the bonding layer so as to form an eutectic seal.

20. An absolute pressure sensor, comprising:

- (a) a semiconductor membrane having a welled portion connected to a planar periphery;
- (b) a substantially nonconductive pad disposed on a portion of the planar periphery of the semiconductor membrane;

(c) a bonding layer, disposed adjacent to the semiconductor membrane and the nonconductive pad; and

(d) a generally planar nonconductive base, having a first and second conductor formed thereon, said generally planar nonconductive base having been bonded to the bonding layer in a vacuum so as to form a vacuum-sealed reference cavity having said first conductor extending therefrom in electrical communication with said semiconductor membrane and said second conductor extending therethrough so as to define a capacitor plate within the vacuum-sealed reference cavity, said second conductor being electrically isolated from the semiconductor membrane by the substantially nonconductive pad.

21. The pressure sensor of Claim 20, wherein the semiconductor membrane comprises doped silicon.

22. The pressure sensor of Claim 20, wherein the first conductor comprises a capacitor plate connected to a lead portion that extends from the vacuum-sealed reference cavity.

23. The pressure sensor of Claim 20, wherein the first and second conductors comprise gold.

24. The pressure sensor of Claim 23, wherein the gold in the first conductor has migrated into the bonding layer and fills any void between the bonding layer and the generally planar nonconductive base proximate to the first conductor to provide a eutectic seal at an interface between the vacuum-sealed reference cavity and the first conductor.

25. The pressure sensor of Claim 20, wherein the bonding layer comprises one of a polysilicon and an amorphous silicon.

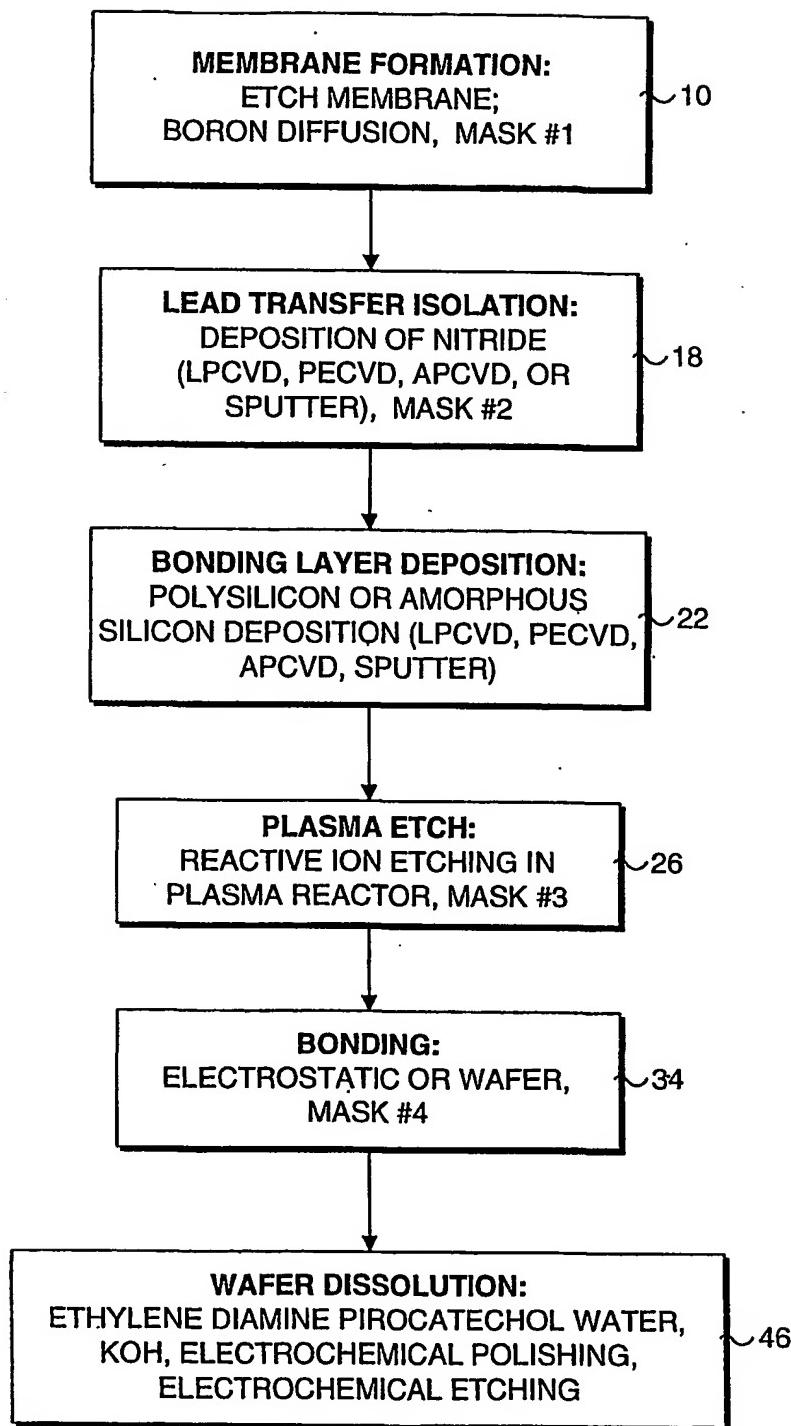
26. The pressure sensor of Claim 20, wherein the substantially nonconductive pad comprises a dielectric material.

27. The pressure sensor of Claim 26, wherein the dielectric material comprises a nitride.

28. The pressure sensor of Claim 20, wherein the substantially nonconductive pad includes a layer of a substantially electrically nonconductive oxide.

29. The pressure sensor of Claim 20, wherein an anodic bond is formed between the bonding layer and the generally planar nonconductive base.

1/6

**FIG. 1**

STEP 1. ETCH RECESS/FORM MEMBRANE

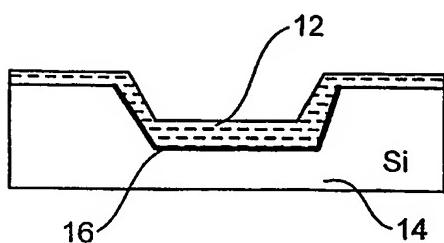


FIG. 2

STEP 2. DEPOSIT DIELECTRIC FOR LEAD TRANSFER ISOLATION

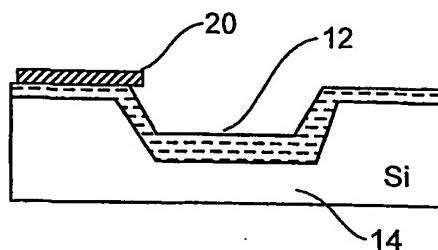


FIG. 3

STEP 3. DEPOSIT BONDING LAYER

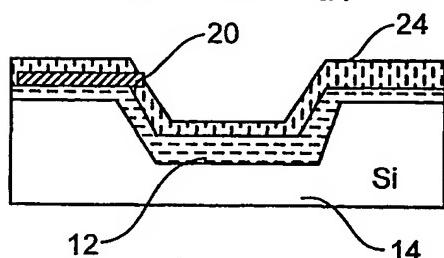


FIG. 4

STEP 4. PLASMA ETCH

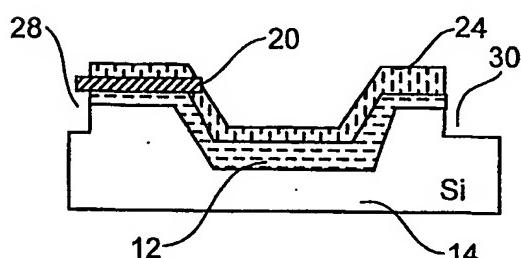


FIG. 5

STEP 5. BONDING

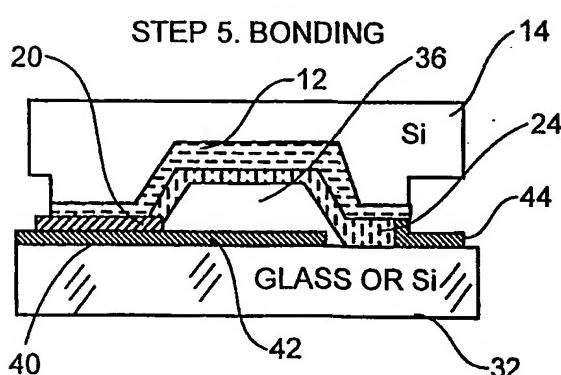


FIG. 6

STEP 6. WAFER DISSOLUTION

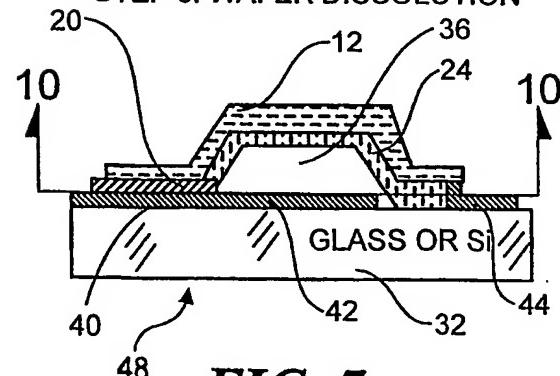
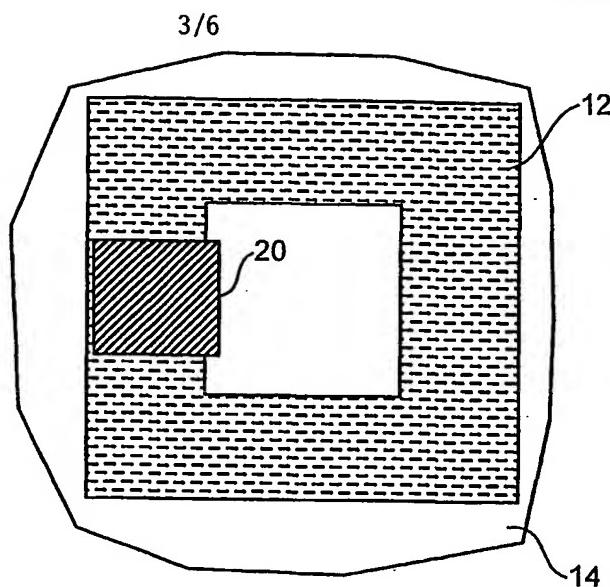
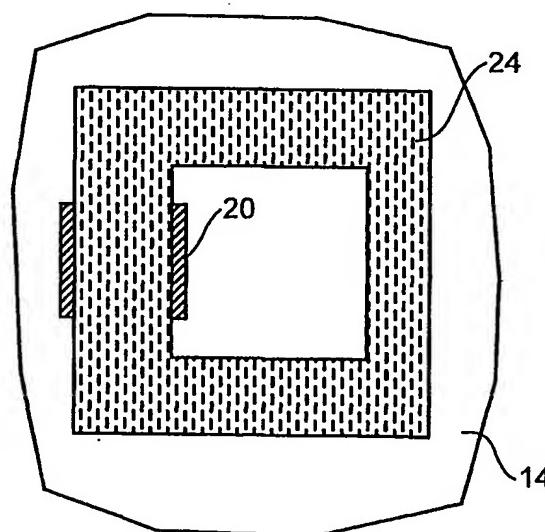
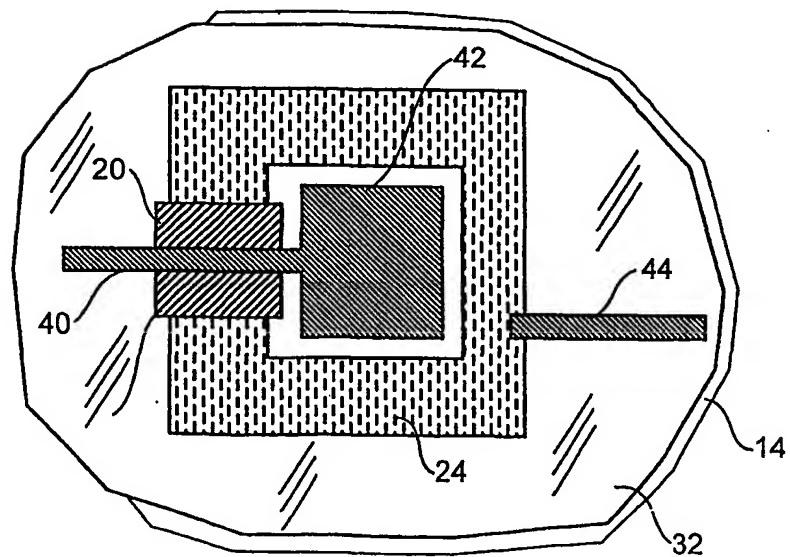


FIG. 7

FIG. 8**FIG. 9****FIG. 10**

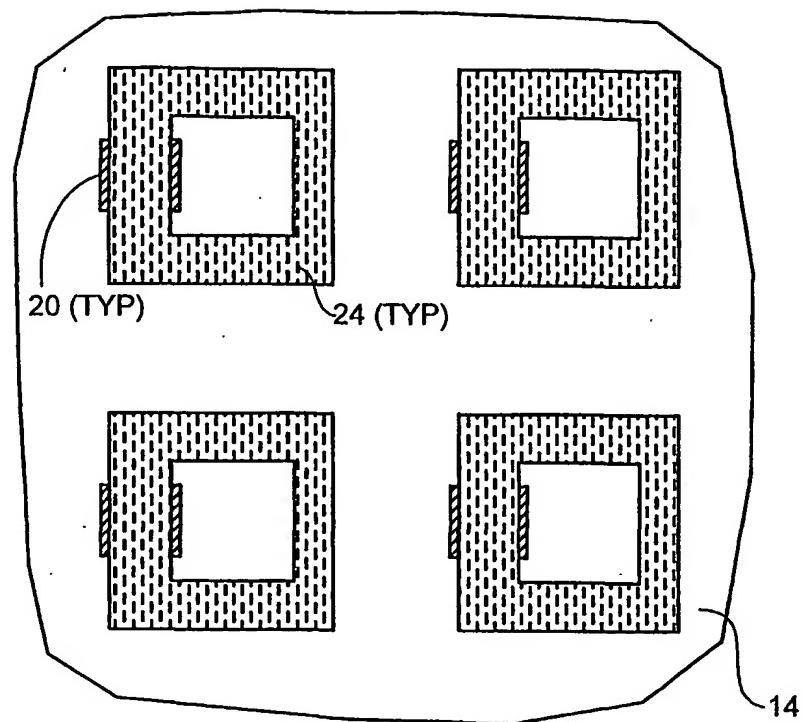


FIG. 11

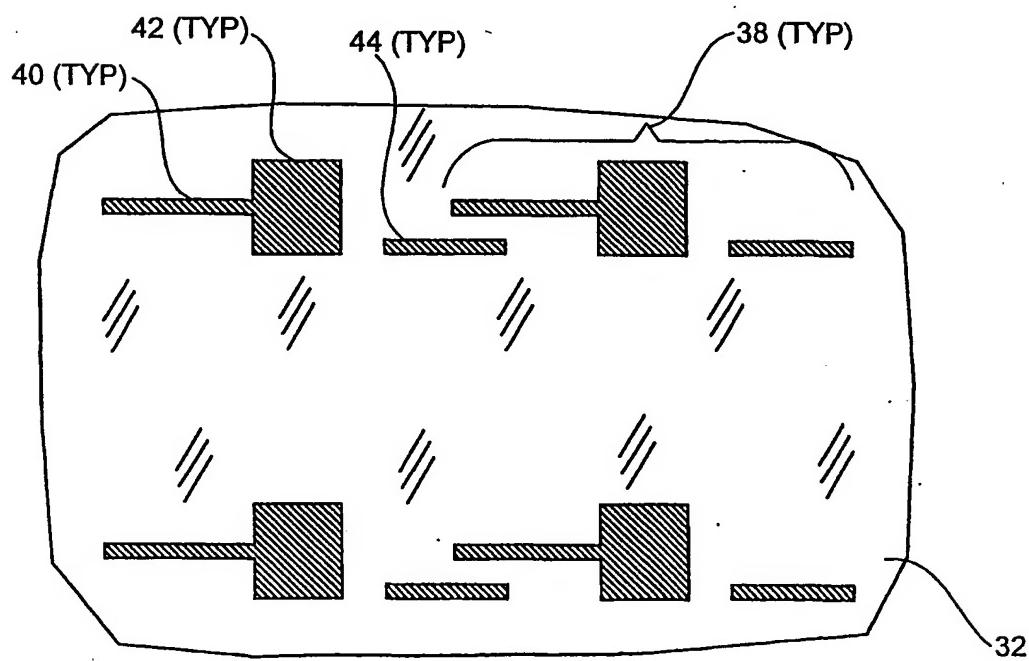
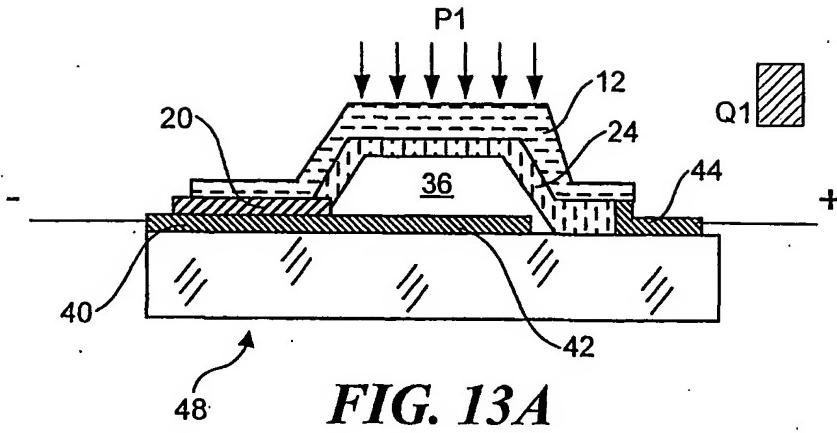
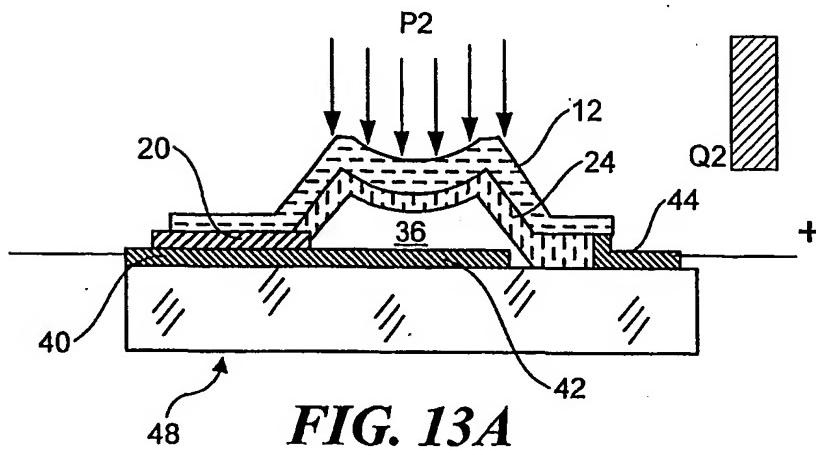
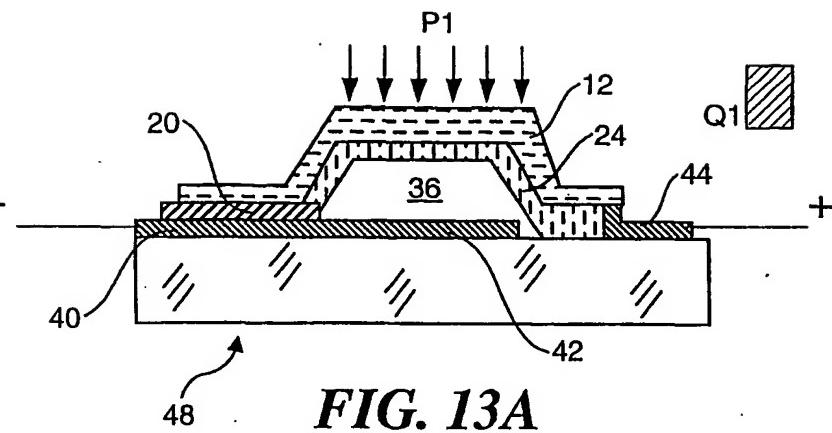
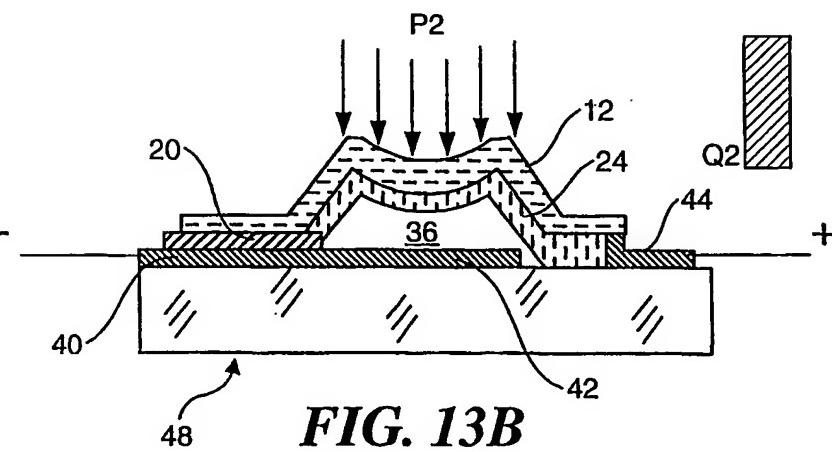


FIG. 12

5/6

**FIG. 13A****FIG. 13A**

**FIG. 13A****FIG. 13B**